NORTH CENTRAL
CLIMATE
SCIENCE
CENTER

**Department of Interior**
**North Central Climate**
**Science Center**

**FINAL REPORT FOR**
**U. S. Geological Survey Award No. G12AC20504**
**CSU contract no. 5-307340**

Project title:
"REVAMP: Resources for Vulnerability, Adaptation, and Mitigation Planning"


Principal Investigator: Dennis Ojima
Institution of PI: Colorado State University


Project Start Date: August 2012
End Date: September 2014 (extended to 30 September 2016)

Total Funding: $936,000

Report Submitted: 16 December 2016

Submitted by:


Dennis Ojima, Principal Investigator, Colorado State University
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# Public Summary:

The North Central Climate Science Center funded research activities in order to provide pertinent climate information to natural resource managers in our region to evaluate impacts of climatic changes and to develop strategies to respond to changes affecting their natural and cultural resources. These funded activities provided improved past and current climate data sets, such as the high resolution temperature data, regional reconstruction. In addition, we have developed climate information from the latest international climate projections. We used this information and additional climate information to evaluate and assess impacts on ecosystem and natural resources. Ecosystem responses were studied across the region and included examples from controls on sagebrush establishment, whitebark pine vulnerability to climate change, grassland dynamics in mountain and prairie areas, and changes in water dynamics affecting water fowl in the prairie pothole area.

Adaptation research efforts and development of strategies with various natural resource managers from federal, state, and Native American communities were carried out. A major focus on drought was defined and the Drought Risk and Adaptation in the Interior (DRAI) research efforts was developed under this funding. We used survey and interviews to gain insights in how various climate changes, especially those related to drought conditions, have been affecting their management practices. This information was important in guiding further research with our management communities related to what climate information would be useful, what impacts are being observed or of concern to these management entities, and what pathways are open to meet changes.

Our research and engagement activities were generated in partnership with National Park Service managers, Native American leaders, and groups working with various non-governmental organizations, such as The Nature Conservancy. In addition, information on climate changes and impacts were incorporated in regional assessment efforts for the Colorado Vulnerability Study.

# Project Summary

The North Central Climate Science Center efforts have been framed as a Resource for Vulnerability, Adaptation, and Mitigation Planning (ReVAMP). **The vision for the NC CSC is a coordinated and integrated regional approach to the management of the nation's land, water, fish and wildlife, and cultural heritage resources that utilizes the best possible understanding of past, present, and future climate into the decision process.** This project has been funded to enable the development and application of ReVAMP to provide the understanding and information needed by decision makers and managers in the region so that a more complete understanding of potential impacts and adaptation strategies for a broad range of natural, cultural, and other resource management activities will be available.

The ReVAMP concept is designed to support information development and to establish partnership with other funded projects and resource managers in our region to enhance their effectiveness. This funded effort has been led by university consortium members at Iowa State University, Montana State University, University of Colorado-Boulder, and Colorado State University (referred to North Central University Consortium or NCUC).

Project outcomes:

- The paleoclimate database consists (Montana State University): 1260 paleoenvironmental records, including proxies of climate (i.e., tree-rings, borehole temperatures, isotopes, diatoms, electrical conductivity, ice cores, loess accumulation), streamflow (i.e., tree rings), fauna (i.e., fossils), vegetation (i.e., pollen, plant macrofossils) and fire (i.e., tree-scars, charcoal) and is hosted at the IoE (http://www.nccscpaleoenvironmentaldatabase.com).
- Historical Daily Temperature Climatology 1948 – 2012 (University of Montana): A 30-arcsec (~800 m) resolution CONUS dataset of 1948 – 2012 daily minimum and maximum temperatures was completed. The historical climatology was implemented through development of an open source statistical framework for modelling topoclimatic air temperature called TopoWx ('Topography Weather').
- Retrospective regional climate simulations for 3 was generated with the WRF model in order to capture detailed orographic precipitation and explicit representation of convective precipitation. The resolution is 4 km, with refined parameterization of the radiation, PBL, and cloud microphysics schemes for the region, and includes monthly T max and T min and monthly precipitation, including snow accumulation during the cold season.
- Object oriented evaluation of climate projections of rainfall was developed with the Asynchronous Regional Regression Model (AARM) downscaled daily rainfall.
- Climate projection data from ARRM (Iowa State University) has been formatted for input into MAXENT model. The BIOCLIM variable in climate projections generated discussion between ISU ecosystem and climate scientists on the uses of the ensemble of climate projections.
- Sagebrush Ecosystems: The application of a process-based daily time-step simulation model to predict yearly big sagebrush regeneration including relevant germination and seedling responses to abiotic factors was conducted. We found that relationships between big sagebrush regeneration and climate conditions were site specific, varying across the distribution of big sagebrush.

- In the Northern Rockies Ecosystem Study: We have the SAHM software running to do SDM. We have also summarized PRISM climate data to calibrate SDMs under present climate and CMIP 5 data across multiple emissions scenarios to 2100. We have simulated presence and absence, as well as abundance, and different tree life-history stages including seedlings and saplings, adults, and mortality for Whitebark Pine, Douglas Fir, and Lodgepole Pine.
- Tallgrass Prairie and Montane Meadow Grasslands: Plant species occurrence records were obtained from field based data collected in 12 study sites in the Grand River Grasslands of Iowa and Missouri. Current (1950-2000) and future (2040's) climate variables were derived at 30 arc seconds (~1km) resolution from the Worldclim dataset (www.worldclim.org). Our results showed that Twenty-eight plant species are predicted to experience reductions in their habitat suitability by 2040.
- In the Rocky Mountain study, regional models of global climate change for the northern Rocky Mountains predict warmer temperatures, diminished amounts of precipitation, and decreased snowpack, which could have significant impacts on the plant community of the region. Woody encroachment was observed as seedlings that were too small to be detected at a 1-meter resolution in the earlier time-period became observable after ~15yrs of growth.
- Prairie Pothole Ecosystems: The distribution and abundance of wetlands in the Prairie Pothole Region (PPR) was evaluated using a Bayesian hierarchical models to incorporate spatial autocorrelation and explicitly estimate spatial variation in wetland abundance. We have modeled the relationship between wetland abundance and covariates describing climatic conditions and land cover.
- The adaptation and decision making support working group was initiated and organized within the social-ecological system framework. This working group is formed to build stronger collaboration between researchers in the social sciences and ecological research areas and between natural resource managers and decision makers in our region.
- The project team developed the framework through an iterative and collaborative process and set of guiding principles. The guiding principles indicated a need for a "nested" framework – i.e., one that adequately captures the complexity and multiple spatial scales of any system, while still allowing for a context-specific focus on particular localized climate vulnerability and adaptation issues that explicitly considered the interactions and feedbacks between social-ecological-climate systems while also considering institutional dynamics and processes of decision making.
- Drought Risk and Adaptation in the Interior (DRAI) Study was developed and implemented. The purpose of this study is to understand how the U.S. Department of Interior's federal land and resource managers and their stakeholders (i.e., NPS, BLM, FWS, BOR, BIA and tribes, among others) are experiencing and dealing with drought in their landscapes. Through expert interviews and surveys we have learned from natural resource managers how they differentially responded and have adapted to drought in the region.

# Introduction to the North Central Climate Science Center

The North Central Climate Science Center (NC CSC) is one of eight regional CSC's under the National Climate Change and Wildlife Science Center (NCCWSC). Our mission is "To provide the best available climate science and tools to inform natural resource management within the North Central domain." The NC CSC is a collaborative, applied research group that works with others across our domain to unite climate science with management decisions. The North Central University Consortium (NCUC), comprised of nine university partners in the region, provides foundational science needs and additional opportunities for integration with climate science users.

# Purpose and Objectives

Starting in late 2012, the NC CSC initiated the first phase of the "Resource for Vulnerability assessment, Adaptation, and Mitigation Planning" (Figure 1) (Morisette, J.T., ed., 2012, North Central Climate Science Center—Science agenda 2012–2017: U.S. Geological Survey Open-File Report 2012–1265, 19 p.). The development of this operational framework emerged from our 2012 Strategic Planning Workshop held in Bozeman, Montana (https://www.doi.gov/sites/doi.gov/files/migrated/csc/northcentral/upload/NC-CSC-science-planning-workshop-report-May-2012.pdf). The ReVAMP concept is a centralizing theme that coordinates research done through the NC CSC and provides a mechanism by which the NC CSC can help serve stakeholder needs. The ReVAMP concept builds on three Foundational Science Areas led by the North Central University Consortium members. The three Foundational Science Areas offer an integrated approach to informing resource managers and researchers in our region:

- ***Climate Drivers:*** Understanding and quantifying drivers of regional climate changes.
- ***Impact Analysis:*** Assessing impacts of climate change on the natural resources of the region and the resulting vulnerability of social-ecological system components.
- ***Adaptation:*** Characterizing adaptive capacity of communities and natural resources.

To address these challenges and to provide usable information for decision makers and resource managers, the North Central Climate Science Center will engage in a set of activities in support of "REsources for Vulnerability, Adaptation and Mitigation Planning". REVAMP will include four focal research areas organized about:

- understanding and quantifying drivers of regional climate changes;
- impacts of climate change on the natural resources of the region and the resulting vulnerability of social-ecological system components;
- characterizing adaptive capacity of communities and natural resource; and
- providing the information to natural resource decision making framework

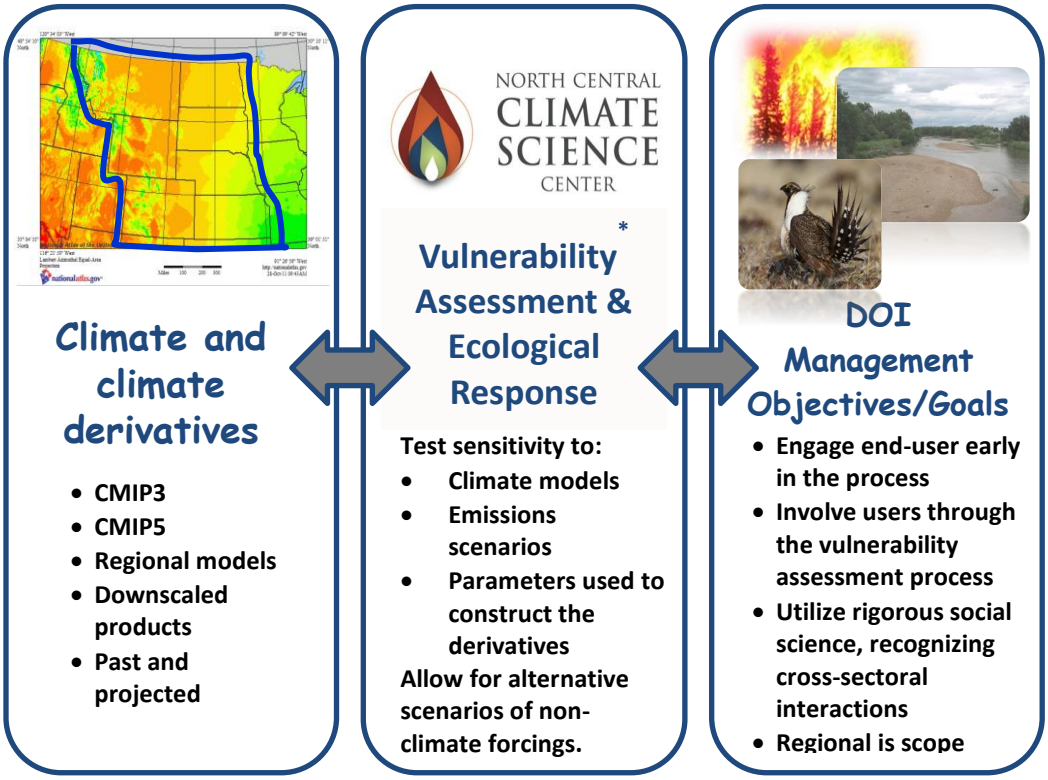



**Figure 1.** The three synergistic NC CSC foundational science areas include physical climate, ecological impacts, and adaptation & mitigation.

# Organization and Approach

Research and analysis along these 4 focal areas was further developed in the project to initiate efforts in the 3 Foundational Science Areas (focal areas 1-3) and to develop and engagement efforts to work more closely with the natural resource management and decision making communities. Based on the input from the Landscape Conservation Cooperatives, members of the SAC, and other resource management entities in the region this initial research project developed the initial framework to conduct research, synthesize knowledge, and create a platform for research and application dialogue.

The strength of the ReVAMP concept is *bringing state-of-the-science climate information into analysis of ecological impacts and in support of adaptation actions in a collaborative and co-production environment which foster knowledge sharing between scientists and practitioners*.

This research element supports vulnerability assessment for climate adaptation (Glick et al. 2011) by focusing on the provision of best available climate information for the region in order to inform analysis of ecosystem exposure to change. The activities associated with this funding were organized along 3 research activities associated with extreme climate dynamics, impact analysis of ecosystem and habitat dynamics, and adaptive capacity and decision making approaches.


Figure 2. Framework for Developing Climate Change Adaptation Strategies (from "Scanning the Conservation Horizon" Glick et al 2011. NWF)

# Project Results, Analysis, and Findings

**FSA 1: Climate and Climate Derivatives: Regional Extreme Climate Events: Gaining Understanding Through Past and Present Observations and Modeling**

*FSA 1 Leads:* **Christopher Anderson**, Iowa State University (TEAM LEADER); **Bart Geerts** (University of Wyoming), **Cathy Whitlock** (Montana State University; **Steve Running**, University of Montana; **Robert Oglesby**, University of Nebraska, Lincoln.

**Climate Science Workgroup in addition to PI's (alphabetical by last name):**

Sheri Fritz (UNeb), Steve Gray (USGS), Bob Gresswell (USGS), Steve Hostetler (USGS), Steve Jackson (UWy), Greg McCabe (USGS), Dave McWethy (MSU), Greg Pederson (USGS), Jasmine Saros (UMaine), Bryan Shuman (UWyo), John Stamm (USGS), Bob Thompson (USGS).

**Overview**

Climate in the North Central United States (NCUS) is driven by a combination that includes large-scale patterns in atmospheric circulation, the region's complex topography extending from the High Rockies to the Great Plains, and geographic variations in water and surface-energy balance. Hydroclimatic variability within the NCUS determines the sustainability of ecosystems in the region as well as the ecosystem goods and services they provide. The project provided 1) databases and climate modeling

results to examine past, current, and projected climate variations and their environmental consequences; 2) developed regional scale future climate projections, 3) provided a region-wide evaluation of changes in water flow, and 4) provided climate information to ecosystems scientists, universities, and stakeholders for targeted ecosystem studies.

Results

- The paleoclimate database consists (Montana State University): 1260 paleoenvironmental records, including proxies of climate (i.e., tree-rings, borehole temperatures, isotopes, diatoms, electrical conductivity, ice cores, loess accumulation), streamflow (i.e., tree rings), fauna (i.e., fossils), vegetation (i.e., pollen, plant macrofossils) and fire (i.e., tree-scars, charcoal) and is hosted at the IoE (http://www.nccscpaleoenvironmentaldatabase.com). Raw data and radiocarbon dates (when applicable) are provided in .csv format for all but tree-ring records, which are available in the NOAA database and a link is provided. We collected metadata for all records. These metadata include site information (i.e., site name, state, coordinates, elevation and modern vegetation), data characteristics (i.e., parameters measured, resolution and span of the record), details on the chronologies associated with the records (i.e., age control, number of radiocarbon dates), authors and publications. Records, derived products and metadata are stored and backed up at the Institute on Ecosystems, MSU.

- Historical Daily Temperature Climatology 1948 – 2012 (University of Montana): A 30-arcsec (~800 m) resolution CONUS dataset of 1948 – 2012 daily minimum and maximum temperatures was completed. The historical climatology was developed through novel integration of weather station reports with remotely-sensed land skin temperature. Prior to data integration, thorough evaluation of station data was conducted. The quality assurance effort found that systematic temporal biases were present in station data at high elevation. A process was developed to remove these biases before data integration. With biases removed, the network's 1991-2012 minimum temperature trend was reduced from +1.16°C decade-1 to +0.106°C decade-1. This important finding suggests that higher elevation and lower elevation minimum temperature trends in the western U.S. are statistically indistinguishable, contrary to previous results. In the context of a warming climate, this artificial amplification of mountain climate trends has likely compromised our ability to accurately attribute climate change impacts across the mountainous western U.S. The historical climatology was implemented through development of an open source statistical framework for modelling topoclimatic air temperature called TopoWx ('Topography Weather').

- As part of the NC CSC the University of Wyoming has conducted retrospective regional climate simulations for 3 years so far. The lead has been Dr. Yonggang Wang, with participation of Chris Anderson, Bob Oglesby, and Roy Rasmussen's group at NCAR, in particular Changhai Liu. This dataset was generated with the WRF model in order to capture detailed orographic precipitation and explicit representation of convective precipitation. The WRF simulations were driven by Climate Forecast System Reanalysis, meaning the WRF data provide an historical simulation that can be compared to observations. The simulation domain stretches from Idaho to eastern Nebraska and Montana to the Texas panhandle. Our domain extends from Washington to Illinois and north into southern Canada, i.e. the North Central region and vicinity. The resolution is 4 km, which is fine enough to resolve deep convection and the details of the

terrain. We have identified the radiation, PBL, and cloud microphysics schemes that perform best, using rigorous statistics, for three parameters. i.e. T max and T min (monthly mean diurnal min and max temperatures) and monthly precipitation, including snow accumulation during the cold season.

- Object oriented evaluation of climate projections of rainfall is being developed with the Asynchronous Regional Regression Model (Stoner 2013) downscaled daily rainfall. ARRM is based upon the 12-km gridded daily rainfall developed by Maurer et al. (2002), and previous research on rainfall swaths described in Goal 1 used these gridded observations. The capability to replicate historical observations can be clearly evaluated with this consistency between observation and downscaled data.

- Climate projection data from ARRM (Iowa State University) has been formatted for input into MAXENT model. A step in this process is the development of code to compute BIOCLIM variables that serve as input to MAXENT. The BIOCLIM variable in climate projections generated discussion between ISU ecosystem and climate scientists on the goals of their project and uses of the ensemble of climate projections to reach their goals.

**FSA 2: Vulnerability Assessment & Ecological Response -** Linkages between Climate and Ecosystem Scientists in the University Consortia

**FSA 2 Team Leads:** Andy Hansen, Montana State University (TEAM LEAD); Diane Debinski, Iowa State University; Bill Lauenroth, University of Wyoming; Barry Noon, Colorado State University
Post-Doctoral Fellows and Graduate Students: Nathaniel B Piekielek, Tony Chang, Hellen Sofaer

Vulnerability refers to the extent to which a species, habitat, or ecosystem is susceptible to harm from climate change impacts (Schneider et al. 2007). Components of vulnerability include exposure to change, sensitivity to change, and capacity to adapt to change (IPCC 2007). Determining which resources are most vulnerable enables managers to better set priorities for conservation action (Glick et al. 2011 Step 3). Understanding why they are vulnerable provides a basis for developing appropriate conservation responses (Glick et al. 2011 Step 4). This research has developed a framework to forecast change in biodiversity response variables under scenarios of climate and land use change in collaboration with research conducted with the Climate working group (see above).

A variety of methods have emerged for analysis of species level vulnerability under climate and land use change. The most frequently used of these methods include climate envelope, niche, and species distribution models (Iverson et al. 2005, McKenney et al. 2011, Monahan 2009, Silero 2011). The NC CSC has expanded its use of workflow and visualization tools can help the niche modeling researcher navigate a logical sequence of model options and track the various results. The Software for Assisted Habitat Modeling (SAHM), implemented as a package within the VisTrails scientific workflow and visualization system, has been created by the USGS and supported for expanded applications were provided by the NC CSC and its staff. SAHM was used to explore climate change impacts on habitat through modeling experiments and facilitated logging the information exchange related to the various input data, pre- and post- processing steps, and modeling options incorporated in the construction of a species distribution models.

We have also acquired and summarized PRISM climate data with which to calibrate SDMs under present climate and CMIP 5 data across multiple emissions scenarios and general circulation models (GCM) to 2100 to represent potential future climates. In order to increase the biological realism of SDMs, we have parameterized and run a Thornthwaite based water-balance model across the GYE that estimates 5 vegetation predictors at monthly time-steps. Water-balance predictors are in addition to roughly 160 potential predictors that we have generated for SDM including numerous (seasonal, annual etc.) summarizations of climate over 30-year periods as inspired by the BIOCLIM project and others, also soils properties, and topographic variables. For response data we have acquired observations from the Forest Inventory and Analysis program, National Park Service Inventory and Monitoring Program, Whitebark Pine Information System and from several individual researchers. We are using these data to model presence and absence of target species, as well as abundance, and different tree life-history stages including seedlings and saplings, adults, and mortality.

Initial efforts worked with existing ecological project supported by the NC CSC through separate funding. The research activities included:

- Sagebrush Ecosystems: Sagebrush and cheatgrass regeneration at leading and trailing edges of the climate change projected sagebrush ecosystem distribution. (W. K. Lauenroth, University of Wyoming)
- Northern Rockies Ecosystems: Dynamics of up to five key ecological system types (e.g., whitebark pine) under climate and land use scenarios across the Greater Yellowstone Ecosystem. (A.J. Hansen, Montana State University)
- Tallgrass Prairie and Montane Meadow Grasslands: Compare and contrast climate change projected changes in Iowa tallgrass prairie and montane meadow ecosystems within the Greater Yellowstone Ecosystem. (D. M. Debinski, Iowa State University).
- Prairie Pothole Ecosystems: Projected climate-induced changes in the distribution, abundance, and quality of wetlands within prairie pothole ecosystems and consequences for waterbirds. (B.R. Noon, Colorado State University)

Results

Sagebrush Ecosystems: Loss of big sagebrush and the decline of associated species, such as greater sage-grouse, are a concern to land managers and conservationists. However, big sagebrush regeneration remains difficult to achieve by restoration and reclamation efforts and there is no regeneration simulation model available. The application of a process-based daily time-step simulation model to predict yearly big sagebrush regeneration including relevant germination and seedling responses to abiotic factors was conducted. We estimated values, uncertainty, and importance of 27 model parameters using a total of 1435 site-years of observation. Our model explained 74% of variability of number of years with successful regeneration at 46 sites. It also achieved 60% overall accuracy predicting yearly regeneration success/failure. We found that relationships between big sagebrush regeneration and climate conditions were site specific, varying across the distribution of big sagebrush. This indicates that statistical models based on climate are unsuitable for understanding range-wide regeneration patterns or for assessing the potential consequences of changing climate on sagebrush regeneration and underscores the value of this process-based model. These results

suggested that seedling survival is a limiting factor, whereas germination is not. Our results also suggested that modeled regeneration suitability is necessary but not sufficient to explain sagebrush presence.

In the Northern Rockies Ecosystem Study: We have the SAHM software running on two computers in our lab and are using it, among other tools, to do SDM. We have also summarized PRISM climate data to calibrate SDMs under present climate and CMIP 5 data across multiple emissions scenarios and general circulation models (GCM) to 2100 to represent potential future climates. A parameterized Thornthwaite based water-balance model has been incorporated for simulations across the GYE that estimates 5 vegetation predictors at monthly time-steps. Water-balance predictors are in addition to roughly 160 potential predictors that we have generated for SDM including numerous (seasonal, annual etc.) summarizations of climate over 30-year periods as inspired by the BIOCLIM project and others, also soils properties, and topographic variables. For response data we have acquired observations from the Forest Inventory and Analysis program, National Park Service Inventory and Monitoring Program, Whitebark Pine Information System and from several individual researchers. We are using these data to model presence and absence of target species, as well as abundance, and different tree life-history stages including seedlings and saplings, adults, and mortality. Results for 3 species including Whitebark Pine, Douglas Fir, and Lodgepole Pine are completed.

Tallgrass Prairie and Montane Meadow Grasslands: Plant species occurrence records were obtained from field based data collected in 12 study sites in the Grand River Grasslands of Iowa and Missouri. Current (1950-2000) and future (2040's) climate variables were derived at 30 arc seconds (~1km) resolution from the Worldclim dataset (www.worldclim.org). We modeled current and future distributions of 31 grassland plant species using the species distribution modeling software Maxent version 3.3.k. Our results showed that Twenty-eight plant species are predicted to experience reductions in their habitat suitability by 2040. For example, very few areas of suitable habitat (Green areas) are predicted to exist for tall fescue (*Festuca arundinacea*) by 2040. Suitability becomes more homogenous for 3 plant species. The climate variables that have the most influence on our predictions are annual precipitation and precipitation in the driest quarter of the year.

In the Rocky Mountain study, regional models of global climate change for the northern Rocky Mountains predict warmer temperatures, diminished amounts of precipitation, and decreased snowpack, which could have significant impacts on the plant community of the region. Changes in the plant community composition could have repercussions across the system. Biotic changes could include modification of the distribution and abundance of insect pollinators or mammalian herbivores; abiotic changes could include modification in fire regimes. Our project goals were to assess changes in vegetation condition and measure woody encroachment in montane meadows of the Greater Yellowstone Ecosystem over the past 15 years, which included several years of mild to extreme drought conditions.

In our analysis we quantified: 1) variation in annual productivity from 2000 to 2012 using MODIS normalized difference vegetation index (NDVI) and 2) the rate and extent of woody encroachment change from 1994 -2011using 15 yrs of National Aerial Photography Program (NAPP) digital orthophotos (DOQs). While we expected that we might see evidence of a long-term drought, the

strongest signal that we observed was recovery from a roughly 10-year drought that lasted from the late 1990s through 2006, with re-entry into drought conditions in 2012. However, interannual variability was much stronger than any longer-term trend in this time-series. With respect to woody encroachment, the primary change that was observed was seedlings that were too small to be detected at a 1-meter resolution in the earlier time-period became observable after ~15yrs of growth. In a small proportion of the meadows, we observed more dramatic conifer seedling encroachment or conifer loss.

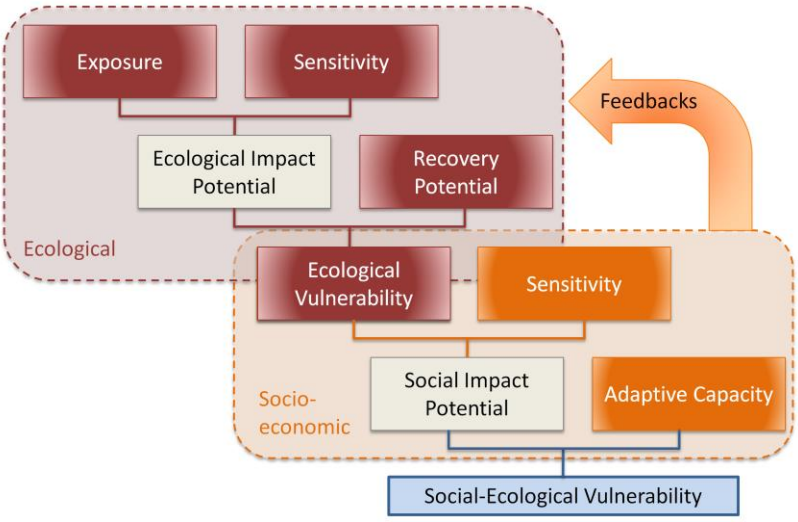
Prairie Pothole Ecosystems: The focus of this project is to model the distribution and abundance of wetlands in the Prairie Pothole Region (PPR), and predict how existing patterns over space may be affected by climate change. We have modeled the relationship between wetland abundance and covariates describing climatic conditions and land cover. Because one of the pressing questions in the PPR is to understand whether climate change may shift the distribution of wetlands towards the east, we used Bayesian hierarchical models to incorporate spatial autocorrelation and explicitly estimate spatial variation in wetland abundance. Our methods therefore provide a powerful new approach for partitioning the variation in wetland abundance that is attributable to measured covariates (temperature, precipitation, the proportion of land cover under agricultural development, and counts of wetland basins) from variation that shows a consistent spatial pattern but is not attributable to these covariates. Ongoing model validation indicates that this model incorporating spatial variation has improved predictive ability over a non-spatial model.

***FSA 3: Adaptive Capacity and Decision Making Framework***

**FSA 3 Co-Team Leads:** Dennis Ojima (CSU) and Shannon McNeeley (CSU);
Working group members: Jill Lackett, Nina Burkardt, Rudy M. Schuster, Andrea Ray, Betsy Neely, Bob Gough, Linda Joyce, Linda Nagel, Carina Wyborn, Cody Knutsen, Jeff Morisette, John Gross, Dan Williams, Geneva Chong, Kristen Averyt, Lisa Dilling, Maria Fernandez-Gimenez, Nicholas Fisichelli, Zhengong Tang, Bill Travis, Stuart Cottrell

Understanding and evaluation of the adaptive capacity of the social-ecological systems in the North Central region is an integral component in the development of management strategies to deal with climate change. In addition, understanding how information related to climate and vulnerability can be incorporated into management strategies can enhance decision making related to managing for change. The vulnerability of natural resources and the adaptive capacity of the social-ecological system vary across the region due to local, state, tribal, and regional accessibility to social-ecological capital resource assets. The availability and use of capital resource assets for implementation of adaptive management practices are critical in the development feasible strategies.

Our efforts in this funding effort focused on:




1. Determine key elements of adaptive capacity across which developing approaches to address natural resource management decisions dealing with climate change dynamics.
2. Analyzing the decision making framework of related to ongoing research efforts of the NC-CSC and related LCC issues
3. Assess current vulnerability and risk assessment methodologies dealing with social-ecological system

Figure 3. Inclusion of social dimensions in vulnerability analysis across our region.

These efforts were aimed to develop our engagement efforts to build a platform for knowledge sharing and enhanced dialogue between resource managers and the climate change research community. In addition, considerations of how to better develop a mechanism to enhance co-production of research efforts and to bridge the management and research communities to enhance development of actionable science efforts within current management objectives. The goal to facilitate co-development of management options which incorporate both long-term and short-term actions and to reduce the implementation of maladapted choices.

Results and related activities

The DOI-sponsored North Central Climate Science Center (NCCSC) in partnership with the USGS Human Dimensions of Climate Change researchers in USGS's Policy Analysis and Science Assistance (PASA) Branch convened two working group sessions – one on April 5th at CSU, and one prior to this on April 3rd at the National Adaptation Forum in Denver - to assess integrated social-ecological vulnerability and adaptation approaches dealing with conservation, land, and resource management targets in the north central region. Participants included staff of the NCCSC University Consortium, USGS scientists, and other university, agency, and community partners were invited to attend.

The adaptation and decision making support working group is organized within the social-ecological system framework. This working group is formed to build stronger collaboration between researchers in the social sciences and ecological research areas and between natural resource managers and decision makers in our region. Currently, NC CSC Adaptation Working group has 43 persons participating, including researchers from Fed Agencies and NCUC and we have conducted several teleconferences and webinars since January.

Social-Ecological Adaptation Framework

The project team developed the framework through an iterative and collaborative process that began in June of 2013. A small interdisciplinary working group worked for the two and a half months prior to the

workshop through weekly phone calls to collectively review relevant literature and plan the workshop agenda. The work group selected a set of seven seminal framework papers from the literature on SES climate vulnerability and adaptation. The framework draws on the insights from leading conceptual work covering vulnerability, adaptation, resilience, and institutional analysis along with linking this type of science to practice (Smit and Wandel 2006; Tuner et al 2003; Moser et al 2010; Chapin et al 2009; Ostrom 2007; Vogel et al 2007). In addition to these conceptual, analytical frameworks, two methodologies identified in the project proposal – a climate change scenario process (Tompkins et al 2008) and an adaptation for conservation targets (ACT) planning process (Cross et al 2012) were revisited in light of insights gained from the other framework papers.

***GUIDING PRINCIPLES FOR SOCIAL-ECOLOGICAL APPROACH TO ADAPTATION***

***Components***

- clear definition of the drivers and attributes of the Social-Ecological-Climate (SEC System)
- comprehensive identification of stakeholders and sectors
- consideration of both climate and non-climate drivers and stressors
- unpacking adaptive capacity, including explicit recognition of institutional barriers and opportunities
- strong climate physical science related to these frameworks make sure best available climate science is informing the framework
- differential vulnerability within the systems
- need to determine baseline vulnerability, existing exposure and adaptive capacity
- attention to politics – political and social inequities that underlie social change

***Scale***

- cross scale linkages, in terms of spatial and temporal scales and indicators
- establishing clear boundaries of the temporal and spatial scale: balancing complexity while balancing over simplification
- unpacking adaptive capacity at multiple scales – facilitate explicit understanding of institutional barriers and opportunities at different scales

***General Approach***

- participatory, iterative stakeholder approach to research breaking down and unpacking what that means and building the relationships to support that
- legitimizing multiple stakeholders' knowledge, and promoting a collective learning of the SES
- breaking down differential needs along the knowledge production and decision making cycle
- linking to decision making process, building the relationships with decision makers
- flexible and adaptive approach

***Approach to Dealing with Complexity***

- avoid oversimplification
- acknowledging and binding complexity
- framework that captures simplicity and complexity
- telescoping and microscoping across the nested scales
- dealing with uncertainty explicitly
- develop differential climate scenarios based on differential vulnerabilities of different sectors
- constant iterative dialogue between ecological, climate and social components
- relationship building

During the August workshop, the team developed a set of guiding principles for the framework. The guiding principles indicated a need for a "nested" framework – i.e., one that adequately captures the complexity and multiple spatial scales of any system, while still allowing for a context-specific focus on particular localized climate vulnerability and adaptation issues. Another guiding mandate was for a framework that explicitly considered the interactions and feedbacks between social-ecological-climate systems while also considering institutional dynamics and processes of decision making. The team also included process-based principles that address need to include the key stakeholders themselves in a participatory research project that is closely connected to and fulfils the needs of Department of Interior and other land managers while producing "useful" and "usable" science that is viewed as credible, salient and legitimate.

The Framework

The guiding principles covered conceptual, methodological and analytical elements of the research project, thus necessitating a framework that integrates across the research topic and process for carrying out the research. The team chose the basic architecture of the Turner et al 2003 framework as the underpinning for the team framework. The nested scales of influence driving climate exposure, vulnerability, adaptive capacity, and resilience and adaptation are captured in the Turner et al framework. The breadth of the Turner et al framework enabled the integration of various aspects of the social, ecological, climate, and institutional dynamics that comprise the core focus of the project. Each of the guiding principles was then superimposed on the Turner framework structure.

The core relationship between human and environmental conditions central to the depiction of social-ecological sensitivity was adapted with the Venn Diagram circles of climate, ecological system, social and institutional dynamics in the center of the diagram. The overlapping circles are intended to graphically represent the co-evolving nature of these three domains; rather than the separation (albeit with feedback dynamics considered) of human and environmental components in the Turner et al framework. The iterative understanding of these domains gained through the scenario process and conceptual/quantitative models of ecosystem dynamics feeds into understanding these co-evolving relationships.

The focus on the role of governance in enabling or constraining resilience and adaptive capacity is captured through an additional element to the Turner et al analytical conceptualization of vulnerability and adaptation. In the box titled "governance" are the guiding principles related to institutional barriers, politics, decision making processes and needs, and social learning that either facilitate or constrain adaptive capacity and responses. The nature of these relationships to vulnerability and adaptive capacity is a core area of inquiry for the research project. Further additions to the Turner et al framework at this scale relate to the differential nature of vulnerability, a need to begin with understanding baseline vulnerability and adaptive capacity, potential barriers to adaptation, and consideration of non- climatic drivers. To move away from conceptualizing environmental conditions as simply "ecosystem services" provided to humans, the need for a clear definition of ecosystem components is included.

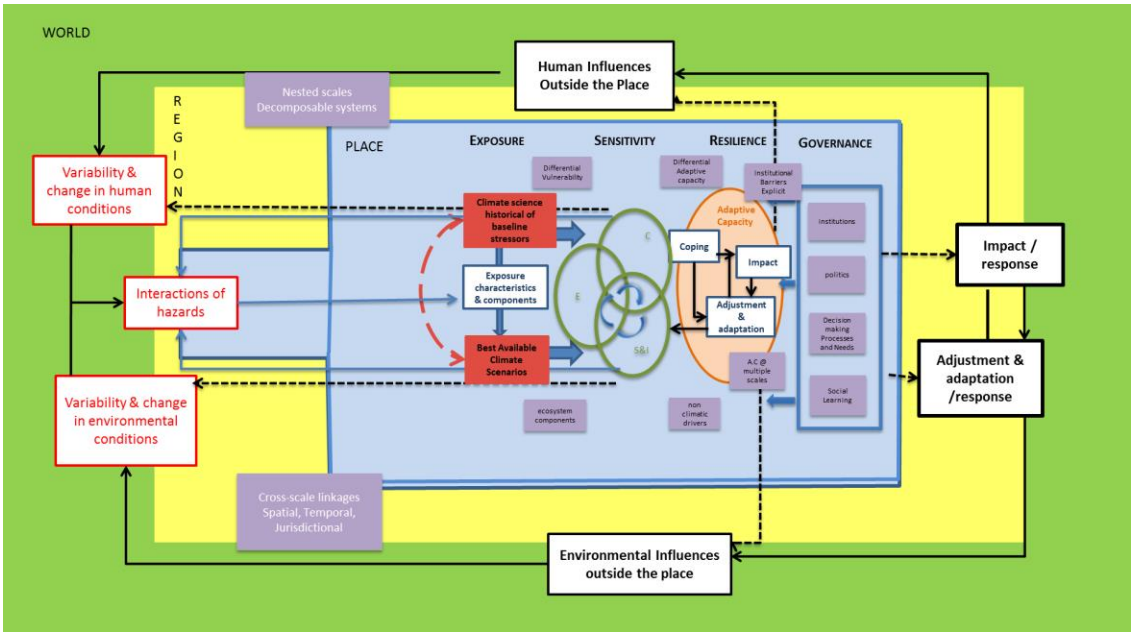



Figure 4 – The framework diagram (Modified from Turner et al 2003)

Zooming out to the larger framework, the analytical focus on nested and cross scale interactions is captured by the Turner et al framework in consideration of the world, the region and the place. Borrowing from Ostrom (2007), the framework adopts an explicit focus on decomposable systems – i.e., systems that have component parts that can be taken apart to analyze pieces of the system most relevant to any given context. The project team conceptualized this as the "microscope and telescope" of different focal scales of interest in the analysis. Zooming the analysis in and out lends to a consideration of cross-scale linkages, meaning, for example, how local-scale policies, economies, or ecosystems are influenced by state- or federal-level policies, and understanding how adaptive capacity and vulnerability manifest at multiple scales; and the interactions and feedback dynamics between those scales.

There are process-based methodological principles for the approach that are not captured in Figure 4. Given this strong desire of the project team to adopt a truly trans-disciplinary and integrative approach, the analytical framework also needed to capture the ongoing-learning and integration through the evolution of the project. While many of the frameworks reviewed implied or could be utilized in a transdisciplinary research context, the process of doing transdisciplinary research in a complex and uncertain arena was not explicitly covered within the frameworks reviewed. Generating usable science for decision-makers is a specific mandate of this project, which necessitates the explicit inclusion of decision-making processes and engagement with stakeholders within overall the framework. Acknowledging and addressing uncertainty was central to the desires of the project team. While many of the papers discussed uncertainty, it was rarely explicitly integrated into reviewed frameworks.

The framework presented here is not intended to be concrete, but rather we consider it to be flexible and adaptive so that as the project evolves with the input from key stakeholders and as team, that learning occurs through various stages of inquiry we can adjust it as needed. The process of creating this

framework, however, allowed the team to come to some common understanding and language for the transdisciplinary approach moving forward. It also grounds the framework in the decades of scholarship on social-ecological climate vulnerability and adaptation that came before it.

Research application on Drought Risk and Adaptation in the Interior (DRAI)

A major focus on drought was defined and the Drought Risk and Adaptation in the Interior (DRAI) research efforts was developed under this funding. The research guidelines for social-ecological system perspectives and adaptation efforts were implemented in this study. We used survey and interviews to gain insights in how various climate changes, especially those related to drought conditions, have been affecting their management practices. The purpose of this study is to understand how federal and tribal land and resource managers and their stakeholders are experiencing and responding to drought in their landscapes. This study looks at two case studies using interviews with public land managers, which guided the analysis of climate data/drought indices and integration to tell "drought stories." Results indicate that local differences in the timing, decisions, and local social-ecological natural resource contexts made a difference in the type of climate data and the requisite temporal and spatial scales of the analyses for each case. These findings suggest that manager- or community-defined scale and social context are critically important to understand the social-ecological milieu in relation to drought indices for guiding appropriate spatial and temporal scales of analysis to inform adaptation and response strategies. This information was important in guiding further research with our management communities related to what climate information would be useful, what impacts are being observed or of concern to these management entities, and what pathways are open to meet changes.

# Outreach and Products

### Capacity-building in the NC CSC Domain

#### *Educational Opportunities*

The NC CSC is providing climate education opportunities and training through cooperation with the National Conservation Training Center (NCTC). The NC CSC is collaborating with the NCTC to provide regional offerings of climate-related courses, which greatly reduces travel costs, eliminates tuition cost for students and covers travel costs for those who require it. In April 2014, we hosted the NCTC Climate Change Vulnerability Assessment class (ALC3184) in Jackson, WY. We had 35 students from our region, HI, AK, CA, and UT, and we look forward to collaborating with the NCTC and the US Fish and Wildlife Service Landscape Conservation Cooperatives (LCCs) in September in LaCrosse, WI. We are excited to develop opportunities for ongoing engagement with our user community through this venue. Currently, the NC CSC plans to partner with the NCTC to offer a tribally-focused "Climate-Smart Conservation" course in Rapid City SD, July 28-30, 2015.

The NC CSC is bringing computing tools, climate data, and management needs together to address complex situations and help stakeholders explore possible future scenarios (Morisette et al 2013). The

NC CSC takes advantage of the Resource for Advanced Modeling, which provides an opportunity to collaboratively address the inherently complex integration of climate data into ecological modeling in a way that directly supports resource management decision making in a changing climate.

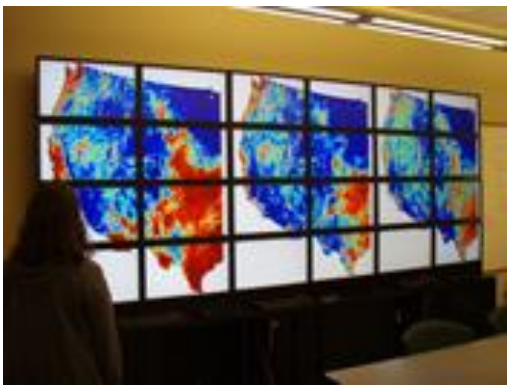


**Figure 2.** The Resource for Advanced Modeling (RAM) "VisWall" is a bank of 24 wall-mounted monitors in a 6x4 array that can be used for displaying large or numerous GIS datasets, photos, or other data products. The image here demonstrates three models of cheatgrass distribution in the western US.

The vision for the NC CSC is a coordinated and integrated regional approach to the management of the nation's land, water, fish and wildlife, and cultural heritage resources that utilizes the best possible understanding of past, present, and future climate in the decision process. Technical components are vital to implementing this vision via downscaling and regionally informed climate projections, ecological response models, and assessing social ecological vulnerabilities and adaptation planning.

The NC CSC activities are organized to provide the best available climate science and inferences on impacts and adaptation strategies for natural resource management entities within the North Central Domain. The NC CSC provides the knowledge and information needed by decision makers in the region so that a more complete understanding of potential impacts and adaptation strategies for a broad range of natural, cultural, energy, and other resource management activities is available. This knowledge and information exchange is provided through the ReVAMP platform to help interpret an array of climate information on changes, impacts, and responses. The aim of these activities is to develop integrated information relevant to our natural resource managers and to ensure that these managers have access to products AND can use them in their decision-making process. The NC CSC is directing its five-year science agenda toward science delivery through ReVAMP. Co-development of research products with managers working in partnership with research groups is a key component of our ReVAMP development efforts.

The NCUC has assembled a team of researchers to lead integrated research activities to enable the NC CSC to provide climate-relevant information to guide decision-making in the region. That is, the NCUC is providing the scientific foundation to be used within the ReVAMP.

### *Native American Indian Engagement*

- Continued DRAI interviews with tribal members at Wind River Reservation, Wyoming and integrating those with the other two DRAI case studies in northwest Colorado and southwest South Dakota in an ongoing effort to build the management-focused interviews for the region
- In September 2014, tribal representatives, scientists, and members of state and federal governments gathered in Rapid City, SD, the ultimate goal of which was to discuss drought and climate change, drought impacts, early warning systems and planning for extreme events with the Missouri River Basin tribes. The workshop was sponsored by the National Integrated

Drought Information Sys- tem (NIDIS). The NCCSC led the coordination of an Inter-Tribal Buffalo Council (ITBC) pre-workshop Representatives from tribes throughout the Missouri Basin region and beyond attended. In addition to the NCCSC and ITBC, partners included NIDIS, the USDA Northern Plains Climate Hub, and the National Drought Mitigation Center at University of Nebraska, Lincoln. The NCCSC continues to support the ITBC in the implementation of their USDA Conservation Integration Grant on Drought Resiliency and Adaptation for their 60 tribal members.

- The NCCSC and other organizations are providing technical support to the Eastern Shoshone and Northern Arapaho tribes on the Wind River Reservation in Wyoming as they establish reservation-wide drought monitoring and planning. NCCSC's Shannon McNeeley, Colorado State University and Gary Collins, Wind River Reservation, are the lead coordinators in this ongoing effort to help the tribes develop a drought monitoring system and drought plan that addresses all 15 beneficial uses of water as identified in the Wind River Tribal Water Code. They are working closely with the Wind River Tribal Water Engineer's office and the Water Resources Control Board. Other participating organizations include the National Drought Mitigation Center at University of Nebraska, Lincoln , University of Wyoming's EPSCoR program, the University of Wyoming Water Resources Data System and State Climate Office, the High Plains Regional Climate Center, the NOAA National Integrated Drought In- formation System, the USDA Northern Plains Climate Hub, and the University of Colorado Boulder-NOAA Western Water Assessment, among many other local tribal partners, water user groups, and state and federal agencies.
- McNeeley led the coordination of a workshop that took place on Oct. 21-22 at Fort Washakie, WY. Workshop sessions and discussion focused on local drought impacts and needs for natural resource management and decision making during drought, the availability of drought and water monitoring data, and on how the tribes could supplement state and federal monitoring programs. Strategies include enlisting volunteer observers on the reservation for the Community Collaborative Rain, Hail and Snow network, and installing and managing weather stations and stream gauges. Participants said that having good climate data will help the tribes better manage the area's water for all of the 15 beneficial uses during times of shortage. A follow-up workshop was held in March 2015 to finalize the summary and to do training on drought planning.
- The Wind River Indian Reservation's vulnerability to the impacts of drought and the development of decision tools to support drought preparedness
- Workshops and Trainings
    - National Conservation Training Center (NCTC)/BIA
    - Rising Voices Collaborative Science with Indigenous Knowledge for Climate Solutions https://risingvoices.ucar.edu/
    - Indigenous Peoples Climate Change Working Group
    - Intertribal Buffalo Council (ITBC) drought workshops

### Other NC CSC Activities

The NC CSC also supports and leads smaller in-house projects and activities that help us to achieve our mission. 2014 activities have included:

### *Joint retreat of NC CSC, WWA, and Northern Plains Climate Hub*

The NC CSC, Western Water Assessment (WWA) and Northern Plains Climate Hub (NPCH) met for a joint and collaborative retreat on November 6-7, 2014 in the shortgrass steppe outside of Fort Collins to set a collective vision and direction for future work. Attendees included representatives from our Foundational Science Area teams, and staff from each of the organizations.

### *Development of a Quarterly NC CSC Newsletter*

The NC CSC has developed a new quarterly newsletter, with the first Fall 2014 issue released in September 2014 focusing on Adaptation. This quarterly publication highlights various aspects of the work that the Center is doing in each of the Foundational Science Areas and Capacity Building, and introduces the public to the NC CSC team, their publications and work, and upcoming opportunities for involvement.

### *NC CSC Monthly Check-ins*

The NC CSC holds monthly check-ins during the fall and spring CSU semesters to feature a presentation by one research team, and allow updates from all research projects for the shared benefit of all NC CSC and project personnel.

### *Contributions to semi-annual SAHM trainings (Capacity Building)*

NC CSC staff members Colin Talbert and Marian Talbert collaborate with the US Geological Survey to hold semi-annual trainings on using the Vistrails habitat modeling software at the USGS Fort Collins RAM facility.

### *Participation in writing and roll-out of the 2014 National Climate Assessment NCANet*

Shannon McNeeley and Dennis Ojima contributed to the 2014 NCA

### *Preparation for 2015 Open Science Conference*

The NC CSC will be hosting its first Open Science Conference May 20-22, 2015. The theme of the conference is, “Integrating Research and Management of Change from the Mountains to the Plains.” Preparation for the conference began in 2014 with invitations sent to potential keynote speakers, arrangements set for meeting space, and communications with NCCWSC on conference and travel allowances. We also began planning and monthly calls with an Organizing Committee (J. Barsugli, W. Day, J. Derner, A. Hansen, D. Ojima and J. Morisette) and NC CSC Conference Coordinators (Lead: J. Lackett).

### *Publications/Presentations:*

Publication

Beever, EA, SZ Dobrowski, J Long, AR Mynsberge and NB Piekielek. 2013. Lack of importance of habitat area and extinction risk for abundance of *Ochotona princeps* across an ecoregion. *Ecology* 94(7):1563-1571.

Behnke, R.J., S. Vavrus, A. Allstadt, T. Albright, W.E. Thogmartin, and V.C. Radeloff. Evaluation of downscaled, gridded climate data for the coterminous United States. Submitted to Ecological Applications.

Behnke, R.J., A. Ballantyne, S. Dobrowski, J.M. Graham, Z. Holden, and S. Running. A recent geographic, seasonal, and diurnal climatology of humidity in the United States using national, regional, and local station networks. In preparation for Journal of Hydrometeorology.

Behnke, R.J., A. Ballantyne, S. Dobrowski, J.M. Graham, Z. Holden, and S. Running. An evaluation of gridded humidity data sets for the United States: Do we still need to estimate humidity? In preparation for Journal of Hydrometeorology.

Biagini, B., R. Bierbaum, M. Stults, S. Dobardzic, and S. M. McNeeley (2014). A typology of adaptation actions: A global look at climate adaptation actions financed through the Global Environment Facility. *Glob. Environ. Chang.*, doi:10.1016/j.gloenvcha.2014.01.003. AVAILABLE ONLINE: http://linkinghub.elsevier.com/retrieve/pii/S0959378014000065

Bierbaum, R., Smith, J., Lee, Arthur…..**McNeeley, S.M**. et al. 2014: Adaptation, *U.S. National Climate Assessment 2014*, U.S. Global Change Research Program

Gordon, E., R. Klein, V. Deheza, and **S. McNeeley**, 2014: Chapter 5 – Water Sector. *Colorado Climate Change Vulnerability Study*, E. Gordon and D. Ojima, Eds., Boulder, CO and Fort Collins, CO.

Gross, J.E., A.J. Hansen, S.J. Goetz, D.M. Theobald, F.M. Melton, N.B. Piekielek, and R.R. Nemani. 2012. Remote sensing for inventory and monitoring of the U.S. National Parks. Pages 29-56 in Y.Q. Yang (ed.), Remote Sensing of Protected Areas. Taylor & Francis, Boca Raton, FL.

Hansen, A.J., N. Piekielek, C. Davis, J. Haas, D. Theobald, J. Gross, W. Monahan, S. Running. In press. Exposure of US National Parks to Land Use and Climate Change 1900-2100. Ecological Applications. http://dx.doi.org/10.1890/13- 0905.1.

Iglesias, V., Krause, T.R., Whitlock, C. 2015. Complex response of white pines to past environmental variability increases understanding future vulnerability. PLOS ONE. DOI: 10.1371/journal.pone.0124439, April 17, 2015.

Kane, K., D. M. Debinski, C. J. Anderson, J. D. Scasta, D. M. Engle, and J. R. Miller, 2016: Grassland Community Restoration in the Face of Climate Change. Submitted to Restoration Ecology.

McNeeley, S. & H. Lazarus (2014) "The Cultural Theory of Risk for Climate Change Adaptation" (in Weather, Climate and Society, Volume 6: Issue 4)

McNeeley, S. (2014). A "toad's eye" view of drought: regional socio-natural vulnerability and responses in 2002 in Northwest Colorado DOI: 10.1007/s10113-014-0585-0 - AVAILABLE ONLINE: http://link.springer.com/article/10.1007/s10113-014-0585-0?sa_campaign=email/event/articleAuthor/onlineFirst

McNeeley, S.M., T.A. Beeton, D.S. Ojima. 2016. Drought Risk and Adaptation in the Interior United States: Understanding the Importance of Local Context for Resource Management in Times of Drought. Weather, Climate, and Society 8 (2), 147-161

Oyler, J.W., S.Z. Dobrowski, Z.A. Holden, and S.W. Running, 2016. Remotely sensed land skin temperature as a spatial predictor of air temperature across the conterminous United States. Submitted to J. Applied Meteorology and Climatology

Oyler, J. W., S. Z. Dobrowski, A. P. Ballantyne, A. E. Klene, and S. W. Running, 2015: Artificial amplification of warming trends across the mountains of the western United States. Geophys. Res. Lett., 42, 153–161, doi:10.1002/2014GL062803.

Oyler, J. W., A. Ballantyne, K. Jencso, M. Sweet, and S. W. Running, 2015: Creating a topoclimatic daily air temperature dataset for the conterminous United States using homogenized station data and remotely sensed land skin temperature. Int. J. Climatol., 35, 2258–2279, doi:10.1002/joc.4127.

Piekielek, N.B. and A.J. Hansen. 2012. Extent of fragmentation of coarse-scale habitats in and around US National Parks. Biological Conservation 155:13-22.

Powell SL, Hansen AJ, Rodhouse TJ, Garrett LK, Betancourt JL, et al. (2013) Woodland Dynamics at the Northern Range Periphery: A Challenge for Protected Area Management in a Changing World. PLoS ONE 8(7): e70454. doi:10.1371/journal.pone.0070454.

Stine, P., P. Hessburg, T. Spies, M. Kramer, C. Fettig, A. Hansen, J. Lehmkuhl, K. O'Hara, K. Polivka, P. Singleton, S. Charnley, A. Merschel. 2013. The Ecology and Management of Moist Mixed-conifer Forests in Eastern Oregon and Washington; a Synthesis of the Relevant Biophysical Science and Implications for Future Land Management. Final Draft. 9 Sept 2013. USDA Forest Service, Portland, OR.

*Presentations*

Behnke, R.J. Development of high resolution gridded dew point data from regional networks. North Central Climate Science Center Open Science Conference, Fort Collins CO, May 2015.

Behnke, R.J., A. Ballantyne, S. Dobrowski, J.M. Graham, Z. Holden, and S. Running. Assessment and improvement of high resolution daily dew point estimation. Annual Meeting of the American Association of State Climatologists, Stevenson WA, July 2014.

Behnke, R.J., A. Allstadt, J. Oyler, and S.J. Vavrus. An evaluation of observationally based, high resolution gridded data sets over the continental United States. National Climate Predictions and Projections Quantitative Evaluation of Downscaling Workshop, Boulder CO, August 2013.

Debinski., D. M. Linking Field Research with Spectral Data to Quantify Interannual Variation in Productivity and Phenology in Grassland Communities. NASA Goddard Space Flight Center, Biospheric Sciences Seminar, Greenbelt, MD, June 1, 2012.

Debinski. D. M. Working with landowners to manage and conserve tallgrass prairie biodiversity: Ecological and sociological challenges and successes. University of Colorado, Boulder, August 30, 2013.

Kane K., D.M. Debinski, C. Anderson, J.D. Scasta, D.M. Engle, and J.R. Miller. 2013. The projected effects of climate change on plant species distributions in grasslands of Iowa. 98th Annual Meeting of the Ecological Society of America, Minneapolis, Minnesota, August 2013.

Oyler, J.W., S. Dobrowski, A. Ballantyne, A. Klene, and S.W. Running (2014), Artificial amplification of elevation-dependent warming in the western U.S. MTNCLIM 2014 Mountain Climate Research Conference, Midway UT, September 2014.

Oyler, J.W., A. Ballantyne, K. Jencso, M. Sweet, S.W. Running, and R. Behnke (2014), A topoclimatic air temperature dataset for the conterminous U.S. Annual Meeting of the American Association of State Climatologists, Stevenson WA, July 2014.

Oyler, J.W., A. Ballantyne, K. Jencso, S.W. Running, M. Sweet, and R. Behnke (2013), A landscape-scale 1948-2012 daily spatial temperature dataset for the conterminous United States. National Center for Atmospheric Research Next Generation Climate Data Products Workshop, Boulder CO, July 2013.

Wang, Y., B. Geerts, C. Liu, 2015: Regional climate simulations of cold-season precipitation and snowpack over the US northern Rockies: validation and examination of factors controlling the precipitation distribution, 27th Conference on Climate Variability and Change, 95th AMS Annual Meeting, Phoenix, AZ, 4-8 January, poster.

Chang, T., A.J. Hansen, N. Piekielek, Tom Olliff. Whitebark pine distribution models under future

possible climates in the GYA. Challenges of Whitebark Pine Restoration Meeting. Whitebark Pine Foundation. Bozeman, MT. Sept 2013.

Chang, T., A.J. Hansen, N. Piekielek, Tom Olliff. Whitebark pine distribution models under future possible climates in the GYA. Poster. Montana Institute on Ecosystems 2013 Science Summit, Helena, MT. Aug 2013.

D.M. Debinski. Linking Field Research with Spectral Data to Quantify Interannual Variation in Productivity and Phenology in Grassland Communities. NASA Goddard Space Flight Center, Biospheric Sciences Seminar, Greenbelt, MD, June 1, 2012.

D.M. Debinski. Working with landowners to manage and conserve tallgrass prairie biodiversity: Ecological and sociological challenges and successes. University of Colorado, Boulder, August 30, 2013.

Kane K., D.M. Debinski, C. Anderson, J.D. Scasta, D.M. Engle, and J.R. Miller. 2013. The projected effects of climate change on plant species distributions in grasslands of Iowa. 98th Annual Meeting of the Ecological Society of America, Minneapolis, Minnesota, August 2013.

Garroutte, E., A. Hansen, N. Piekielek. Using NDVI and Fecal Chlorophyll to Predict the Relationship between Grassland Phenology and Herbivore Ecology in the Greater Yellowstone Ecosystem: Validation and Human Land Use. Poster. Montana Institute on Ecosystems 2013 Science Summit, Helena, MT. Aug 2013.

Hansen. North Central Climate Sciences Workshop. Nov 2012 Hansen.
Ecological Society of America meeting. Aug 2012.

Hansen. Zool Soc of London & Wildlife Cons Soc Symposium on protected areas, Nov 2012.

Hansen. Montana EPSCoR meeting. Feb 2012.

Hansen, A.J. et al. Landscape climate change vulnerability project. NASA Ecological Forecasting Annual Scientists Meeting. Washington D.C. April 2013.

Hansen, A.J., N. Piekielek, C. Davis, J. Haas, D. Theobald, J. Gross, W. Monahan, S. Running. Exposure of US National Parks to Land Use and Climate Change 1900- 2100. Society for Conservation Biology Annual Meeting. Baltimore, WA. July 2013.

Hansen, A.J., S.W. Running. Focus 3: Understanding impacts of climate change through ecosystem modeling and vulnerability assessment. Montana Institute on Ecosystems 2013 Science Summit, Helena, MT. Aug 2013.

Hansen, A.J., H. Naughton, E. Shanahan, N. Piekielek, T. Chang, T. Olliff. Informing implementation of the Greater Yellowstone Coordinating Committee's Whitebark Pine Strategy based on climate sciences. Challenges of Whitebark Pine Restoration Meeting. Whitebark Pine Foundation. Bozeman, MT. Sept 2013.

Nelson, R., A.J. Hansen, H. Naughton, E. Shanahan, N. Piekielek, T. Chang, T. Olliff. Informing implementation of the Greater Yellowstone Coordinating Committee's Whitebark Pine Strategy based on climate sciences. Poster. Montana Institute on Ecosystems 2013 Science Summit, Helena, MT. Aug 2013.

Ojima, D.S., S.M. McNeeley, J.T. Morisette. Presentation on "Social – ecological framing of climate change adaptation strategy development of managing natural resources." At ISSSRM Conference, Estes Park. June 6, 2013

Ojima, D.S. and S.M. McNeeley. Panel Discussion on the National Climate Assessment findings. Colorado State University. March 13, 2013.

Ojima, D.S. Overview of NC CSC. At the workshop on Climate Change Effects on Riparian Tree

Seedlings 2013 Stakeholder Workshop. Ft Collins Science Center, March 7, 2013

Ojima, D.S., S.M. McNeeley, J.T. Morisette. Invited Presentation to Colorado TNC on "Overview and Research Perspective on Social-Ecological Systems". TNC Office, Boulder, CO, 22 May 2013

Ojima, D.S. and others. ESA Ignite talk on "Great Plains Regional Climate Assessment". ESA Annual Meeting, Sacramento, CS, 12 August 2014.

Ojima, D.S. Invited presentation to National League of Cities (NLC) Energy, Environment and Natural Resources (EENR) on "LOCAL PERSPECTIVE ON CLIMATE CHANGE ADAPTATION AND RESILIENCE: Comments on Research enabling Practice based on the National Climate Assessment and the Great Plains Region". City of Fort Collins, 5 September 2014

Ojima, D.S. Invited speaker on: "Water System Vulnerability to Climate Change across the US and for Colorado: Reflections from the National Climate Assessment and the Colorado Assessment Studies" for the Colorado State University Interdisciplinary Water Resources Seminar. 15 September 2014

Ojima, D.S., S.M. McNeeley, J. T. Morisette. ESA invited talk on "Adaptive capacity of socioecological systems under climate change in north central United States". ESA Annual Meeting, Minneapolis, MN, 11 August 2015

Ojima, D. S. Panel Discussion to Eagle County Commissioners' Community Conversations on Climate Change. Edwards, CO, 17 March 2016.

Ojima, D.S. Panel member at the CSU 2016 Focus on Climate Smart Agriculture. 5 May 2016.

Ojima, DS, G Senay, T Hilinski, B Flynn. Presentation on "What kind of Droughts Matters?" ESA Annual meeting, Fort Lauderdale, FL, 11 August 2016

Ojima, D.S. invited presentation to the National Agricultural Research, Extension, Education and Economics Advisory Board on "Climate Change Partnerships, Stakeholders, and Knowledge Co-Development". Colorado State University 21 October 2016

Piekielek, N. Climate and land use change modify the patch dynamics of green forage in the Upper Yellowstone River Basin Poster. Montana Institute on Ecosystems 2013 Science Summit, Helena, MT. Aug 2013.

Piekielek, NB. and AJ Hansen. 2012. Biophysical controls on grassland phenology in the Upper Yellowstone River Basin and implications for conservation under climate change. Montana Chapter of Society for Conservation Biology Annual Meeting. Bozeman, MT.

Piekielek, NB. 2012. Remote sensing grassland phenology in the Greater Yellowstone Ecosystem: biophysical correlates, land use effects and patch dynamics. The 11$^{th}$ Biennial Scientific Conference on the Greater Yellowstone Ecosystem. Mammoth, WY.

Steen,V.A., S.K. Skagen, B.R. Noon. Poster presentation. Impacts of climate on distribution and habitat use by migrating shorebirds in the Prairie Pothole Region. Western Hemisphere Shorebird Group meeting. Santa Marta, Colombia. September 2013.

Steen,V.A., S.K. Skagen, B.R. Noon. *In Revision.* Towards assessing vulnerability of breeding waterbirds in the Prairie Pothole Region, U.S.A. Submitted to PLoS One.

### Student Involvement.

Graduate students:

- Colorado State University: Valerie Steen has been refining species distribution models for wetland-dependent birds in the PPR.
- Montana State University: Tony Chang, Regan Nelson, and Erica Garroutte, in addition to being involved in continuing science activities, have contributed to 6 presentations and 8 workshops or trainings.
- Kim Szcodronski will be participating in a climate change vulnerability assessment workshop in WY in Oct. Undergraduate Sarah Klein worked in our lab during spring 2013 as a volunteer assistant on the project.

Postdoctoral Student Involvement.

- Postdoctoral research associate Kristin Kane has contributed to 1 publication and 2 presentations.
- Nathan Piekielek (MSU) has contributed to contributed to 4 publications, one funded research proposal, 7 presentations, and 6 workshops or trainings.
- Dr. Helen Sofaer (CSU) has helped design our research direction and a lead role in engaging managers.

# CONCLUSIONS AND RECOMMENDATIONS

The North Central Climate Science Center funded research activities in order to provide pertinent climate information to natural resource managers in our region to evaluate impacts of climatic changes and to develop strategies to respond to changes affecting their natural and cultural resources. Efforts have been initiated under this funding to enhance our engagement with various resource management entities and to further develop a platform to support co-production of knowledge to enable responding to climate changes.

These funded activities provided information on what climate information would be useful in developing assessments of impacts and adaptation strategies in different environmental and institutional settings across the region. Ecosystem responses were studied across the region and included examples from controls on sagebrush establishment, whitebark pine vulnerability to climate change, grassland dynamics in mountain and prairie areas, and changes in water dynamics affecting water fowl in the prairie pothole area. Adaptation research efforts and development of strategies with various natural resource managers from federal, state, and Native American communities were carried out. A major focus on drought was defined and the Drought Risk and Adaptation in the Interior (DRAI) research efforts was developed under this funding. This information was important in guiding further research with our management communities related to what climate information would be useful, what impacts are being observed or of concern to these management entities, and what pathways are open to meet changes.

Our research and engagement activities indicated that co-production efforts provided an improved mechanism to develop the appropriate information related to climate, impacts, and adaptation needs to decision makers that was more readily usable. These efforts should be further developed with the ReVAMP framework.

The focus on drought across the region proved to be a useful nexus of climate, impacts, and natural resource management decision making which guided our efforts to provide more actionable activities in support of natural resource managers and researcher engaged in our efforts across the NC CSC region.

These findings, efforts, and process of co-production of activities and knowledge related to climate change and how to respond climate change should be useful in further state, regional, and national climate change assessments in the future.

North Central Climate Science Center on the web
http://www.doi.gov/csc/northcentral/
http://www.revampclimate.colostate.edu/
Reports:
Five Year Science Agenda: http://pubs.usgs.gov/of/2012/1265/
2012: http://www.doi.gov/csc/northcentral/upload/NWCSC_AnnRpt12_043013-FINAL-low-res-1.pdf
2013: http://revampclimate.colostate.edu/sites/default/files/documents/NCCSC_AnnRpt13.pdf

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